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SUGGESTIONS FOR A QUANTITATIVE MINERALOGICAL CLASSIFICATION OF IGNEOUS ROCKS

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It is with considerable hesitation that the writer introduces a new classification of igneous rocks. He knows that he who adds a single term to an already overburdened vocabulary is looked upon with disfavor, while he who brings in many has hearty objurgations heaped upon him; yet he hopes, as others who have gone this way before him have hoped, by fixing definite boundary lines beyond which the different families cannot pass, to eliminate the multiplication of names for rocks which differ in no essential particulars from previously described types.

It is being recognized, more and more, that there is need for three classifications of igneous rocks. Of these, one must be for field use[1] and megascopic. Another must be chemical, after the manner of the systems of Osann[2] and C.I.P.W.[3] The third must be mineralogical. The old classifications of Rosenbusch and Zirkel are more or less mineralogical, it is true, and are not to be discarded lightly, but they fail especially in their lack of the quantitative element. Furthermore, they are neither purely mineralogical, purely chemical, nor purely geological. For example, certain dike-rocks are classified by Rosenbusch, on the basis of their field associations with nephelite-syenites, essexites, etc., as rocks of the alkali series, and to them he gives specific names, yet they are mineralogically and chemically identical with normal rocks of the alkali-lime series. He depends in part, therefore, on field associations

[1] Field classifications are given by Cross, Iddings, Pirsson, and Washington, *Quantitative Classification of Igneous Rocks* (Chicago, 1903), p. 180; L. V. Pirsson, *Rocks and Rock Minerals* (New York, 1908), p. 202; Albert Johannsen, "Petrographic Terms for Field Use," *Jour. Geol.*, XIX (1911), 317–22. A revised form of the latter will appear shortly.

[2] A. Osann, *Tschermak's Mitteilungen*, XIX, XX, XXI, XXII (1899–1903).

[3] Cross, Iddings, Pirsson, and Washington, *op. cit.*

for classification. Elsewhere he uses chemical data to classify rocks which he defines in mineralogical terms; for example, the SiO_2 percentage must lie between certain limits, or the sum of the alkalies must be less than the alumina, etc.

Another objection to the present system of classification is the fact that rock terms have been used loosely or with different meanings. Thus dolerite, originally applied to a coarse basalt, has been used for any dark rock, and in England is used for rocks which we call diabases. The term diabase in the United States means a dike-rock with an ophitic texture, yet it was originally used for Paleozoic basalts and is still so used in various countries. Basalt has been applied to plagioclase rocks with augite and olivine irrespective of the kind of feldspar, to labradorite-pyribole[1] rocks with or without olivine, to the darker labradorite-pyribole rocks, to post-Tertiary extrusives of gabbroic magma, etc.

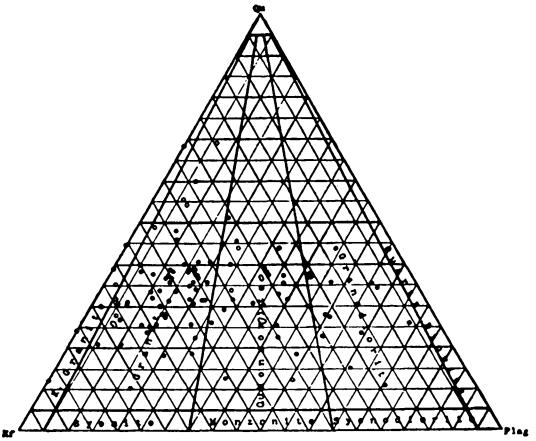


FIG. 1.—One hundred and nine so-called "granites." Open circles are rocks of Class 1, and dark circles rocks of Class 2. The double circle is the mean of Daly's granites recomputed into the probable modal minerals.

The loose usage of terms by different writers with respect to the mineralogical compositions of rocks is well brought out by Figs. 1 and 2, in which the three corners of the triangles represent respectively quartz, potash-feldspar, and plagioclase. In Fig. 1 are plotted 109 so-called "granites," taken, not from old descriptions, but from comparatively recent ones in which the actual mineral compositions were determined by the Rosiwal method or by careful estimation by the various writers themselves. In a few cases the rocks were doubtless named on the basis of their

[1] A general term for the members of the pyroxene and amphibole groups (Albert Johannsen, *op. cit.*).

chemical compositions, but in most cases their chemical compositions are as far from true granites as are their mineral compositions. The figure shows that there are actually 6 potash-granites (one of them quartz-rich), 63 normal granites (4 of them quartz-rich), 29 quartz-monzonites (1 of them quartz-rich), and 11 granodiorites. Fig. 2 represents 30 so-called "syenites." There are 2 potash-syenites, 3 normal syenites, 14 normal granites, 3 monzonites, 7 quartz-monzonites, and 1 granodiorite.

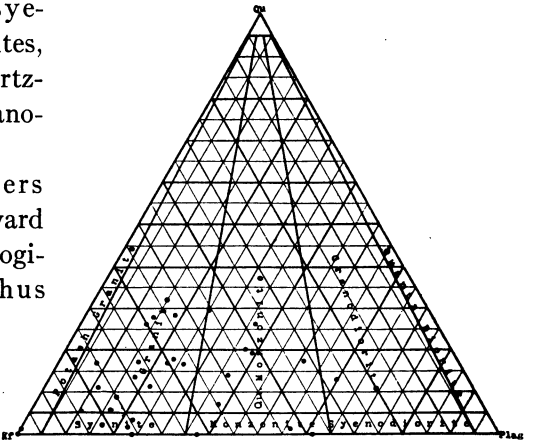


FIG. 2.—Thirty so-called "syenites"

Many recent papers show the tendency toward a quantitative mineralogical classification. Thus Brögger proposed fairly definite boundaries for monzonite and quartz-monzonite. From the latter Lindgren separated granodiorite, and established limits so clearly that almost all rocks described as granodiorites are actually such. But covering a wider field are later papers by Iddings[1] and Lincoln.[2] Each of these writers proposed a definite classification, and more recently Shand[3] suggested subdividing rocks according to their percentages of light and dark constituents. To the writer, none of these classifications appears so satisfactory as that which he has presented to his students, with various modifications, during the past seven years. The system was first thought out in the summer of 1909, and even so long ago as the summer of 1910 the writer prepared plaster models of tetrahedrons, cut into subdivisions essentially as shown here. Owing to press of other work and lack of

[1] Joseph P. Iddings, *Igneous Rocks* (New York, 1913), Vol. II.

[2] Francis Church Lincoln, "The Quantitative Mineralogical Classification of Gradational Rocks," *Econ. Geol.*, VIII (1913), 551–64.

[3] S. J. Shand, "A Recording Micrometer for Geometrical Rock Analysis," *Jour. Geol.*, XXIV (1916), 404.

sufficient data in the literature as to the modes of rocks, the publication was delayed. In the present paper the writer presents the system in a tentative form, hoping to receive from other petrographers expressions of opinion and suggestions for modifications. Later he hopes to show the relationships, both mineralogical and chemical, existing between the rocks falling into the various groups.

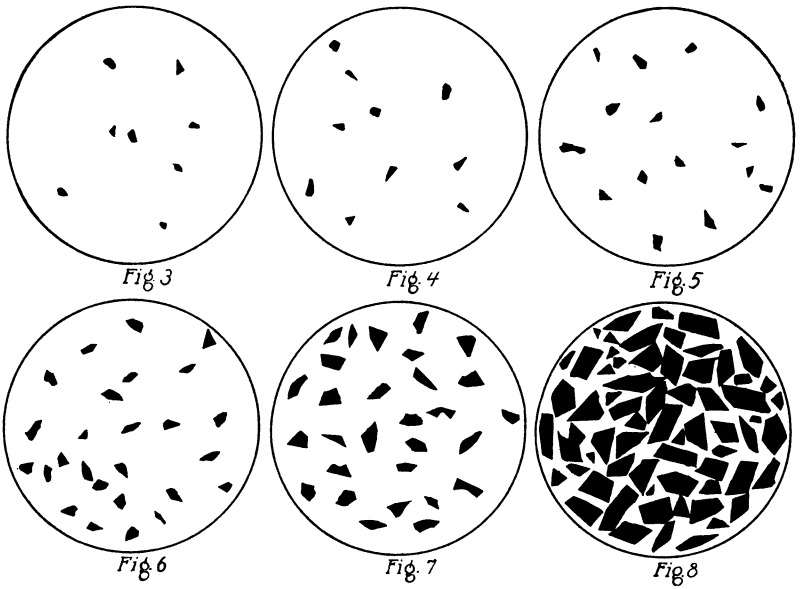
The system here proposed is strictly mineralogical, quantitative, and modal, and is directly applicable to all plutonites and to practically all extrusives. The writer's objections to the percentage values set by various other authors will be given below. Apparently the dividing lines have previously been arbitrarily selected, and no attempts have been made to gather published data with respect to the modes of rocks. There is, in fact, a surprising lack of such data, the writer having been able to find published reports of less than 600 quantitatively determined rocks.

If the reader has ever attempted to find, from the average report, the relationship existing between a newly described rock and the older types, he will in many cases have found it impossible. This is clearly shown by the fact that Rosenbusch himself, by the misinterpretation of descriptions, has misplaced rocks, grouping them with totally unrelated types. If the reader will turn at random to almost any petrographic report,[1] and will read a description and then attempt to picture to himself the rock described, in most cases he will find that owing to lack of quantitative data no idea as to its appearance can be obtained.

A name should convey an idea as to the character and appearance of a rock, and it should not be necessary, as it now unfortunately is, for one to read the description of a rock to know what a writer means. So far as the name itself is concerned, it is of slight importance, provided the texture is described and accurate quantitative details of the average rock are given. But without quantitative details serious errors may arise. Thus in a recent petrographic report a rock was said to contain orthoclase, andesine, quartz,

[1] The writer is guilty of having written indefinite descriptions himself. As an exception to the general rule of poorly written and indefinite reports, he likes to refer his students to Dr. H. S. Washington's "Roman Comagmatic Region," *Carnegie Publication No. 57*. Here there is never the least doubt as to the mineralogical composition and appearance of a rock.

biotite, and hornblende, and was called a syenite. One naturally would suppose from the name that andesine and quartz were of subordinate importance, yet an examination of many thin sections showed 20 per cent quartz and 30 per cent each of orthoclase and andesine, a rock which is a quartz-monzonite BRÖGGER. One rock found to be thus incorrectly named raises doubts as to the accuracy of the determinations of all other rocks in the same report.



FIGS. 3–8.—Various proportions of dark minerals in a rock

During the past few years the writer has required his students, in their rock descriptions, to give the percentages of the different constituents,[1] and he has invariably found that the estimates of the less abundant minerals, such as the dark constituents in leucocratic rocks or the light constituents in those that are melanocratic, are entirely too high, and that the first summation of all the constituents runs between 80 and 95 per cent. The reader may test for himself, before reading farther, his ability to estimate percentages by examining Figs. 3 to 8, which were made by pasting

[1] For a specimen card showing percentages see Albert Johannsen, *A Manual of Petrographic Methods* (New York, 1914), p. 614.

into circles of known size irregular fragments cut from pieces of black paper which bore definite ratios to the circles.[1] Of course, if one has often measured constituents by the Rosiwal method his estimates are likely to be fairly good.

The system here presented is not intended as a substitute for any chemical system. But, as so well expressed by Clarke, "Even if it [the C.I.P.W. system] should be finally adopted by all petrologists, some form of classification like that now in vogue would have to be retained with it. Good analyses cannot be obtained for every rock which the geologist is called upon to determine, and in many cases he must be content with the results of a microscopic examination."[2] And it is also true that for rocks which show considerable decomposition the microscopic method is far more likely to give good results than the chemical.

As an objection to a quantitative mineralogical system, such as is here proposed, it will be said that it is not always possible to determine the exact composition of rocks with a glassy base or extrusive rocks of the alkali series. But the percentage of indeterminable rocks is comparatively small, and for these there still remain, if necessary, chemical methods for determining the composition of the base. Most glassy rocks are leucocratic, and a recalculation into the minerals which would have crystallized had the conditions been right is easy. Since the majority of these glassy rocks are rhyolitic, one is no worse off in adopting a quantitative classification than at the present time, when they are called rhyolites from microscopic examination. In such cases it would not be objectionable to make use of tentative names which could be revised after chemical analyses have been made. In a later paper the author hopes to present a method for determining quantitatively even these rocks with very little difficulty. Certainly 95 per cent of fresh igneous rocks can be classified microscopically. When rocks are completely decomposed, no determinative system, chemical or mineralogical, will help.

The plutonic rocks must necessarily form the type families of any mineralogical classification of igneous rocks, and extrusive

[1] The actual percentages in the figures are ½, 1, 2, 5, 10, and 50.

[2] F. W. Clarke, "Data of Geochemistry," *U. S. Geol. Surv., Bull. 616*, (Washington, 1916), p. 432.

and hypabyssal rocks must be regarded as modifications of these. In this paper the writer has given names only to the plutonic representatives of the few families considered, it being understood, of course, that the granite family includes rhyolites; the syenite family, trachyte; the monzonite, latite; etc.

The basis of the classification here proposed is a double tetrahedron (Fig. 9), each trihedral angle of which represents certain mineral constituents. If there were a geometrical figure having ten or twelve corners, each equally distant from each of the others, it would have been possible to use a single mineral at a corner. Since there is no such figure, and rocks must be located with reference to all of the minerals which occur in them, it was found necessary to divide the minerals into as many groups as there are corners in a tetrahedron. But quartz and the feldspathoids never occur together, so it was possible to make the classification in five dimensions by using two tetrahedrons with a common base (Fig. 9). This arrangement was found to answer the purpose admirably, for the relationships between rocks which may contain either quartz or nephelite, etc., and which appear anomalous in the old classifications, are clearly shown.

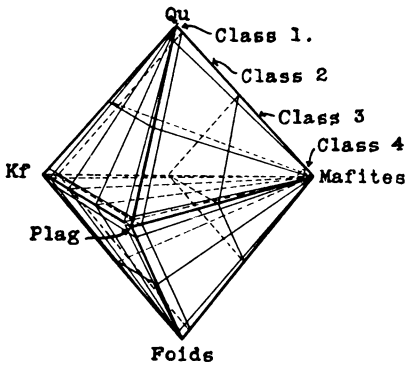


FIG. 9.—Subdivisions of the double tetrahedron into classes.

The groups of minerals represented by the corners of the double tetrahedron are: (1) quartz (symbol Qu[1]); (2) potash feldspars (symbol Kf), including the orthoclase molecule in anorthoclase;

[1] In the figures in this paper the quartz corner is indicated by the symbol Qu. The letter "f" is used for feldspar, therefore Kf indicates the potash-feldspars—orthoclase, microcline, and the orthoclase molecule in anorthoclase; Naf indicates albite and the soda molecule in anorthoclase, while Ca*Na*f represents the acid plagioclases and Na*Ca*f the basic plagioclases, the element in excess being given in italics temporarily to avoid confusion, although there need be none if one thinks of the symbol as reading calcium-bearing soda feldspar for the acid plagioclase and soda-bearing calcium plagioclase for the basic. Caf is used for anorthite, and Foids for the feldspathoids, lenads being unavailable from its use for certain normative minerals of the C.I.P.W. system.

(3) all plagioclases and the albite molecule in anorthoclase; (4) all feldspathoids; (5) the mafites,[1] including the ferromagnesian constituents, the "ores," etc., as given below.

As shown in Fig. 9, the double tetrahedron is unsymmetrically divided on certain faces by the traces of planes parallel to the quarfeloid[2] faces; on others, by lines parallel to one side as well as by lines converging to one of the angles. Experiments were made with symmetrical divisions of various kinds, but it was found impossible to fit the rocks as now named into compartments so made. It is true that new names might have been devised for such subdivisions, but it was not thought desirable to discard entirely the old and well-tried classifications which have very much to recommend them besides the fact that they have been so long in use. The old classifications are unsymmetrical, for we speak of a rock as a quartz-syenite, quartz-monzonite, quartz-diorite, etc., when it contains any amount of quartz. With respect to this mineral, therefore, the classification is based upon its ratio to the sum of all the other constituents, and the lines of division must be parallel to a side of the tetrahedron. The same is true also of the feldspathoids. In the divisions according to the feldspars, however, we find, for example, that a rock is a quartz-monzonite whether the percentage of feldspar among the light constituents is 10 or 90. Here the divisions are based upon the ratio of the feldspars to each other, irrespective of what their amount may be in the rock. The division lines, therefore, must converge toward the quartz and feldspathoid corners, as shown in Fig. 9.

[1] When the writer proposed (*Jour. Geol.*, XIX [1911], 319) the term "femag" as a substitute for ferromagnesian minerals which are not minerals of the norm, he did not stop to consider its euphony or whether it fitted into the C.I.P.W. terminology, but thought of it only as a term to take the place of "femic," which was being misused. He is perfectly willing to substitute "mafic" as an adjective, as proposed by the authors of the C.I.P.W. system (*Jour. Geol.*, XX [1912], 561). He wishes to use here a term for all the dark minerals of a rock except those that are pneumatolytic, and therefore uses "mafite" as a noun, feeling at liberty to include in it, since the word has not been used before, certain iron minerals, as listed below.

[2] C.I.P.W. suggest "felsic" as an adjective for the minerals quartz, feldspars, and feldspathoids. The writer here uses "quarfeloids" (QUARtz, FELdspar, feldspathOIDS) as a noun for these minerals in the front faces of the double tetrahedron, "felsite" being unavailable from its use as a rock name. "Leucocrates" cannot be used, since all light-colored minerals are not included.

The igneous rocks may be divided into various *classes* according to the percentage of dark constituents present. Any number of divisions might, of course, be made; Shand[1] proposed twelve, though more for descriptive purposes than classificatory. It is, however, not desirable in a classification to multiply excessively the number of classes into which the rocks are divided, and they may be gathered into rather large groups. Tentatively four classes have been made: (1) rocks with less than 5 per cent of dark constituents, (2) dark constituents between 5 and 50 per cent, (3) dark constituents between 50 and 95 per cent, and (4) dark constituents more than 95 per cent. Now since these division lines represent planes parallel to the two quarfeloid planes (quartz-feldspars and feldspars-feldspathoids), Fig. 9, they form similar triangles whose sizes represent the amounts of light constituents, decreasing with increase in dark constituents and approach to the mafite corner. For convenience, however, since they are similar they may be represented by triangles of the same size.

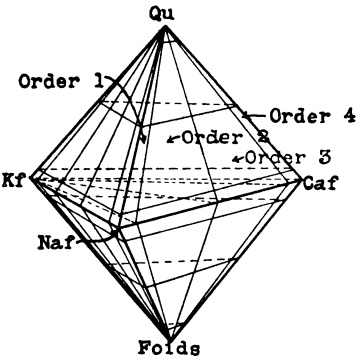


FIG. 10.—Subdivisions of the secondary double tetrahedron into orders.

Thus far the classification is one of five dimensions. But this is not enough. The kind of plagioclase in the rock must be taken into consideration. To bring this factor into the classification, imagine the lozenge-shaped quarfeloid plane to consist of two sheets of paper fastened together only along the Qu-Kf-Foids edge. If now the loose corners of the two sheets be separated a distance equal to a side of the original triangle, a new double tetrahedron will be developed, the horizontal line along which it was opened representing all plagioclases, the ends being formed by the Ab and the An molecules (Fig. 10). The same thing can be done, of course, with the double triangles representing the other classes, and the classification will now be made up of four double tetrahedrons,

[1] S. J. Shand, *op. cit.*, p. 404.

one for each class, the corners being formed by quartz, potash-feldspar, albite, anorthite, and the feldspathoids. But these tetrahedrons may be subdivided into *orders*. Based on the old classifications, these orders depend upon the proportions of the albite to the anorthite molecule; consequently the divisions must be made by planes all of which cut the quartz–potash-feldspar–feldspathoid edge but separate across the central plane of the double tetrahedron, as shown by the dotted lines in the figure, or by Fig. 11, which is a horizontal section through the center. That is, the edge Qu-Kf-Foids remains common to all of the divisions, the plagioclase corner simply having been changed. Now while the triangles formed by the intersections of these planes with the tetrahedron (Fig. 10) are not all equilateral, *the relative position of any rock plotted on an equilateral triangle on the basis of the three components represented by its corners and reduced to 100 will be the same as the same rock plotted with four components within the solid tetrahedron.* Consequently the different orders also may be represented simply by a series of double equilateral triangles (Figs. 20–23 or 24–26) whose right-hand corners vary with the kind of feldspar. It would, of course, be possible to make 20 or 100 or more different orders based upon variations of 5 or 1 or some other percentage in the albite content, but this is neither desirable nor necessary. Here the divisions have been made (1) albite ($Ab_{100}An_0$ to $Ab_{95}An_5$), (2) oligoclase and andesine, (3) labradorite and bytownite, (4) anorthite (Ab_5An_{95} to Ab_0An_{100}), giving four orders. In other words, the dividing points between albite and anorthite are 100–95–50–5–0 of the albite molecule.

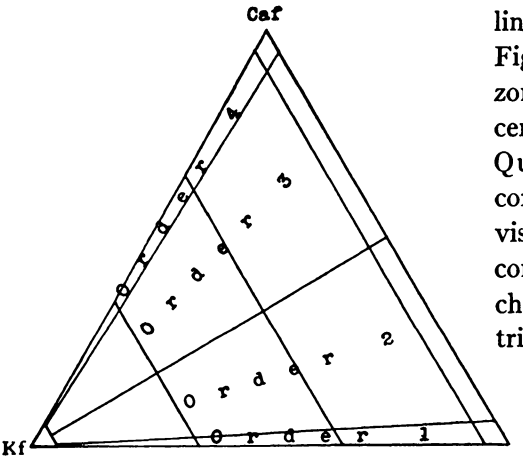


FIG. 11.—A section through the central plane of Fig. 10

There are now six dimensions in the classification, and since each pigeonhole will represent not only a plutonic rock but also a hypabyssal and an extrusive, we may say we have a classification in seven dimensions, yet every rock may be shown by a single point on a drawing in a single plane. The more detailed description which follows may make this clearer.

NUMBER AND POSITIONS OF THE VARIOUS DIVISION LINES

Classes.—The dividing lines between the various classes, orders, families, etc., were not selected at random, but an attempt was made to see if they have any logical positions. For this purpose the writer has been collecting data on cards for all rocks whose modes in mineral percentages have been determined. The number is small, less than 600 such rocks having been found. Unfortunately this number is too small to determine definitely all points, but the writer found that in most cases preliminary graphs with fewer analyses showed practically the same curves as the ones here given.[1]

In order to determine the positions of the dividing planes between the light and the dark rocks, and to decide whether there should be four or five classes (namely white, light, medium, dark, and black), the rocks of the various families were plotted in Fig. 12, in which the abscissae represent the proportions of light constituents in the rock and the ordinates the number of rocks whose modes were known, the percentages being gathered by fives to make a smoother and more representative curve than the individual percentages would have made. The lower curve in the figure is the curve of *all* rocks (585) of which the writer had the modes, and includes the alcalic rocks as well as the families given in the upper curves. All the curves except the one for gabbro, which does not extend so far, show an increase at 90–95 per cent light and a decrease beyond that toward 100 per cent. Consequently rocks may well be called leucocratic when there are 95 per cent or more of light minerals; and there is no objection to making the melanocratic division beyond 95 per cent dark. A difficulty appears in

[1] Since this paper was written, 91 additional mode-analyses have been found, but the graphs remain practically as they were.

making a third division. In the granite and syenite, monzonite and quartz-monzonite, syenodiorite and granodiorite families a line separating 50 per cent light from 50 per cent dark would throw practically all of the rocks on the same side. With respect to diorite and quartz-diorite the curve is not good, owing to insufficient data, and it shows no definite maximum. The gabbro-curve has its maximum at 60 per cent light. With the gabbros

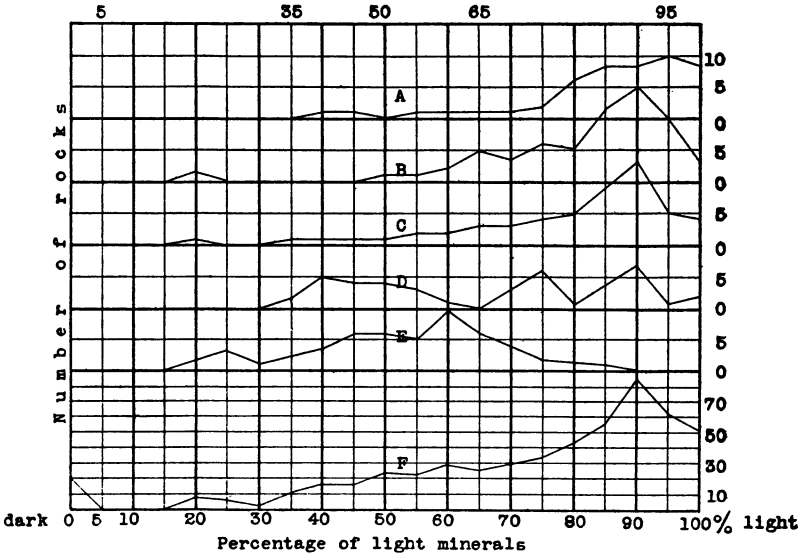


FIG. 12.—Curves showing the number of rocks with various percentages of light and dark constituents: *A*, granite and syenite; *B*, quartz-monzonite and monzonite; *C*, granodiorite and syenodiorite; *D*, quartz-diorite and diorite; *E*, quartz-gabbro and gabbro; *F*, all rocks.

and diorites it might be better to make five classes with dividing lines at 0–5–35–65–95–100 instead of at 0–5–50–95–100, yet the 65 per cent light line cuts the gabbro-curve at rather a high point. The addition of a fifth class for rocks with approximately equal amounts of light and dark constituents would increase the total number of families by 104, and to the writer it seems undesirable to do this. Not much is gained, and it is just as well to speak of light and dark gabbros, separating on the 50–50 line, as to make the main gabbro class the intermediate 35–65 position. In the lowest curve, which

represents all rocks, there are no sharp division lines except at 5 and 95 or thereabout. The central division points could equally well be 50–50 or 35 and 65. On the whole, the writer thinks the 50–50 line best, but leaves this question open for the present.

Lincoln[1] makes three divisions, leucocratic, mesocratic, and melanocratic, according to the percentages of light constituents, with division lines at 0–33–67–100; and in the expanded series, five divisions at 0–4–33–67–96–100.

Iddings[2] separates his rocks on the ratios $0–\frac{3}{8}–\frac{5}{8}–100$; that is, into rocks with less than $37\frac{1}{2}$ per cent dark, between $37\frac{1}{2}$ and $62\frac{1}{2}$ per cent, and with more than $62\frac{1}{2}$ per cent. This makes the first and third groups very large. Even the C.I.P.W. general subdivisions of $0–12\frac{1}{2}–37\frac{1}{2}–62\frac{1}{2}–87\frac{1}{2}–100$ would make the first and last groups too large, for rocks with $12\frac{1}{2}$ per cent of dark constituents (see Fig. 7 with 10 per cent) certainly are not leucocratic. Furthermore, a division at $12\frac{1}{2}$ or $37\frac{1}{2}$ per cent at the leucocratic end is not so logical as at 5 per cent (cf. Fig. 12). Shand[3] makes his divisions at 100–97–90–80–70–60–50–40–30–20–10–3–0 per cent light minerals. These, however, are too many for the purpose of classification, the essential difference between rocks with 60 and 70 per cent of dark constituents, for example, being insignificant. From the curves in Fig. 12 there appears to be little choice between dividing lines at 33, 35, $37\frac{1}{2}$, or 50. If there is any, it is in favor of 50–50.

Orders.—Having divided the rocks into four (or five) classes according to the amount of dark constituent, they may be divided into orders on the basis of the plagioclase.

In determining the kind of plagioclase in a rock, it has been quite customary to give the Ab-An percentage in simple round numbers, such as Ab_2An_3, Ab_1An_1, etc. This produces an excessive number of rocks at these points, as is clearly brought out in Fig. 13, which is less valuable for that reason. As may be seen, there are crests at Ab, Ab_3An_1, Ab_2An_1, Ab_1An_1, Ab_3An_5, and Ab_0An_{100}. Having no other marked crests in the curve indicating natural division lines, the writer has taken the points 0–5–50–95–100,

[1] F. C. Lincoln, *op. cit.*, 556.

[2] J. P. Iddings, *op. cit.*, II, 150, 308.

[3] S. J. Shand, *op. cit.*

thus grouping albite (allowing up to $Ab_{95}An_5$ for latitude), oligoclase and andesine, labradorite and bytownite, and anorthite (with Ab_5An_{95} for latitude), and conforming to the present lines of separation between the alkali rocks, the acid plagioclase (dioritic) rocks, the basic plagioclase (gabbroic) rocks, and the anorthite rocks.

Each of the first three classes of rocks may be divided in this manner into four orders, making twelve orders in all. The fourth class, that is, the one in which the dark constituents form over 95 per cent of the rock and the light constituents, including the feldspars, only 5 per cent, naturally cannot be divided on the basis of the feldspars; consequently its orders are differently formed.

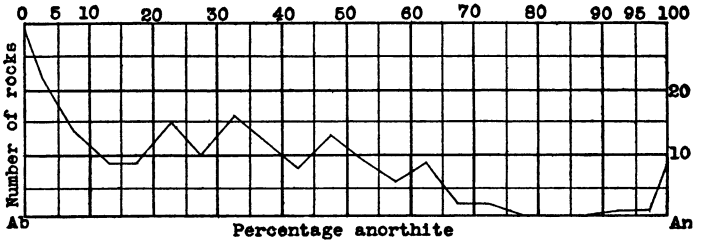


FIG. 13.—Number of rocks with various plagioclases, all families from 0 to 31 included.

Lincoln does not divide his rocks on the kind of plagioclase, but separates his gabbro from diorite, for example, simply on the basis of its leucocratic or mesocratic character, which is not according to common usage.

Iddings[1] unites his orthoclase with albite and uses the ratio of orthoclase plus albite to other plagioclases, and makes his divisions[2] at the points $0-\frac{7}{1}-\frac{5}{3}-\frac{3}{5}-\frac{1}{7}-100$; that is, at $0-12\frac{1}{2}-37\frac{1}{2}-62\frac{1}{2}-87\frac{1}{2}-100$ per cent. These divisions are not quite comparable to the present writer's triangular divisions into the Kf, Naf, and Caf ratios. Owing to the fact that soda is of more importance in connection with the lime of the plagioclases than it is in connection with the potash of cryptoperthite, it seems more reasonable to separate Kf from Naf+Caf than to separate Kf+Ab from the plagioclase minus albite. The latter would be simpler in placing microperthite, but

[1] J. P. Iddings, *op. cit.*, II, 41. [2] *Ibid.*, pp. 38, 40–41, 42, 44.

is incorrect in theory. Tyrrell[1] says that Iddings' system is faulty in this respect, and suggests uniting all the soda molecules with orthoclase, and comparing the sum with the lime molecules. But to this the objection may be made that it fails to separate the soda- from the potash-rocks. Personally the writer prefers to go one step farther and separate the three molecules, as shown in Fig. 11. If Kf and all the Naf were united, it would make difficulty in the monzonite group where the Ab molecule must be separated from the An. Thus with the potash and soda united, a rock with 50 per cent orthoclase and 50 per cent andesine ($Ab_{60}An_{40}$) would give $(Or+Ab)_{80}An_{20}$, while if classified by the ratio of orthoclase to albite plus anorthite it would give Or_{50} $Plag_{50}$. The difficulty in determining the albite in most microperthite is not great; the amount can be estimated with little error.[2] Of course this is not possible in anorthoclase, and rocks containing much of this mineral will have to be determined chemically. Ordinarily, however, the amount of soda is too small to change the classification of the rock, even if neglected. In rocks which contain known amounts of soda-orthoclase and plagioclase, the molecules must be separated. Thus a ciminite from the Roman Comagmatic Region[3] contains soda-orthoclase (Or_6Ab_1) 43.6 per cent and labradorite (Ab_1An_2) 16.1 per cent, which gives orthoclase 37.4 per cent and albite 6.2 per cent from the soda-orthoclase, and albite 5.4 per cent and anorthite 10.7 per cent from the labradorite. Uniting these there is orthoclase 37.4 per cent, albite 11.6 per cent, and anorthite 10.7 per cent. This gives $Ab_{52}An_{48}$, the point falling just on the Ab side of Ab_1An_1 or in Order 2, and $Kf_{63}Plag_{37}$, which brings the rock in the row of families 3, 8, 13, etc. (Fig. 16). Zonal feldspar may be determined by considering the approximate amounts of each kind and obtaining the average Ab-An value. This will be necessary in but few cases, for ordinarily it may be determined by inspection whether the

[1] G. W. Tyrrell, "A Review of Igneous Rock Classification," *Science Progress*, No. 33 (July, 1914), 79.

[2] For figures giving a comparison of measured and calculated values see Eero Mäkinen, *Bull. com. géol. Finlande*, No. 35 (1913), p. 74; Charles H. Warren, *Proc. Amer. Acad. Arts and Sciences*, LI (1915), 127–54.

[3] H. S. Washington, *op. cit.*, p. 65.

average runs across the $Ab_{50}An_{50}$ line. Of course if the nucleus as well as the rim falls entirely between the 0–5, 5–50, 50–95, or 95–100 lines, there is no need for computation unless it be to determine the exact position of the rock in the triangle.

Families.—The quarfeloid face of the double tetrahedron (Fig. 9), or any face parallel to it, will appear as shown in Fig. 16. To locate thè lines separating the various families it was necessary to determine the logical divisions in two directions; namely, between

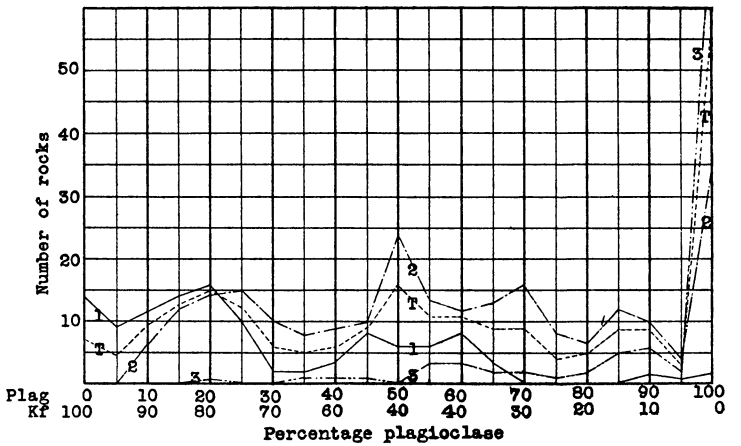


FIG. 14.—Ratios of Kf to plagioclase in Families 1 to 15, Orders 1 to 3, and totals. Vertical scale of totals is one-half of other curves. The numbers indicate the orders.

the potash feldspar and the plagioclase and between rocks with or without quartz or feldspathoids.

In Fig. 14 the curves for the proportions of potash-feldspar to plagioclase are shown for Orders 1, 2, and 3 and for the sum of all feldspathoid-free rocks; the writer having no mode-analyses showing potash-feldspar with anorthite in Order 4. The curves show rather excessive increases on the 50–50 line, due to the fact that many writers speak of labradorite as Ab_1An_1; the deduction of rocks where this was done would slightly reduce the lines. In all the curves the dividing lines may be made at 0–5–35–65–95–100, corresponding to the subdivisions in vogue of alkali-granite, granite, quartz-monzonite, granodiorite, quartz-diorite, etc.

The vertical direction of Fig. 16 gives the quartz percentage. In Fig. 15 are plotted the curves for the proportion of quartz among the light constituents for all rocks in the upper triangle (Families 0 to 15, Fig. 16), and separate curves for Orders 1, 2, and 3. The separation at 5 is clear. There may be a question whether the upper division of quartz should be made at 95, 90, or even at 65. For symmetry, of course, it should be at 95. With respect to a line at 50, the writer is in doubt. Practically all the rocks fall below 50 per cent quartz (that is, quartz is less than 50 per cent of the

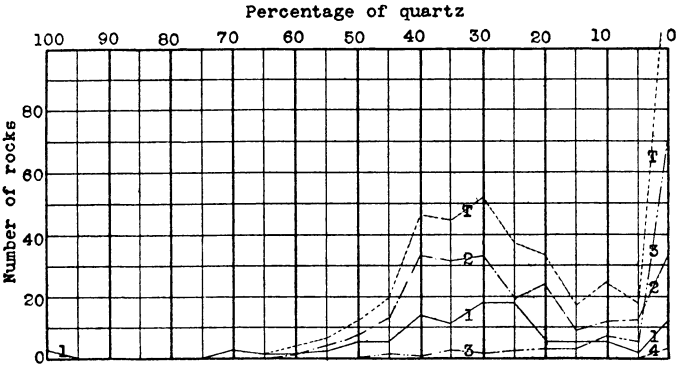


FIG. 15.—Percentage of quartz among the light constituents, recalculated to 100. Curves for Orders 1, 2, 3, 4, and totals. The numbers indicate the orders.

light constituents, consequently it forms even less than 50 per cent of all the constituents of the rock). It would be possible to group all the rocks given in Families 2 and 7, 3 and 8, 4 and 9, etc. (Fig. 16), together, and call those falling in the upper divisions simply quartz-rich granites, etc. However, since there are so few rocks here, it may make it all the more desirable to divide on the 50–50 line. This would make uniform divisions everywhere in the system at 0–5–50–95–100 except for the Kf-Plag ratio. Of course the retention of the line at 50 in this and the lower triangle makes 8 or 10 more families in each order of the first three classes, or a total of 102. However, if these families are simply numbered and the rocks called quartz-rich granite, quartz-rich granodiorite, nephelite-rich nephelite-syenite, etc., it will add no new names and make clearer the positions of the rocks. Curves drawn for the

feldspathoid rocks are similar to those in Fig. 15, but are somewhat more irregular owing to insufficient data.

The families are to be numbered as shown in Fig. 16. The object in beginning with 0 is to make the positions easier to remember, since they run in groups of five. Furthermore, Family 0 occurs only in Order 1, as do also Families 1, 6, 11, 16, 21, 26, and 31, for they form the hinge about which the order tetrahedron (Fig. 10) was opened, and are the same in all. This is shown in Figs. 21 to 23, where these families are omitted and represented by dotted lines. Instead of having 12×32 families, therefore, there are 3×32 families (in the first orders in each of the first three classes) $+9 \times 24$ families (in Orders 2, 3, and 4) $+3 \times 15+1$ families (in Class 4, to be mentioned later), making 358 families in all. If Order 1 is omitted, as suggested in question 4, below, the total families will be 286, and if Order 4 is united with Order 3 there will be only 214. Although the maximum number of families is 358, it does not mean that there are 358 names to learn, for the light and dark rocks may be separated by prefixes without making awkward names; thus leuco-granite, melano-granite, etc.

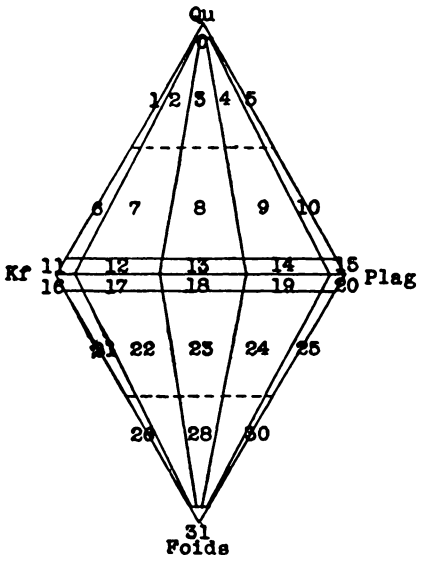


FIG. 16.—Family numbers in Classes 1 to 3.

The divisions made by other writers may now be compared with Figs. 14 and 15. Lincoln uses the ratio orthoclase to all plagioclase, the latter not differentiated as is done here. His percentages are 100–96–67–33–4–0.

It is rather difficult to compare the divisions proposed by Iddings with those proposed by Lincoln or by the present writer, for, as mentioned above, he unites albite with the potash feldspar and

compares this sum with the remaining plagioclase; that is, he has the ratio

$$\frac{\text{Kf+Ab in albite}}{\text{Ab in soda-lime feldspar+all An}}.$$

His divisions are,[1] as mentioned under "Orders," above, 100–87½–62½–37½–12½–0.

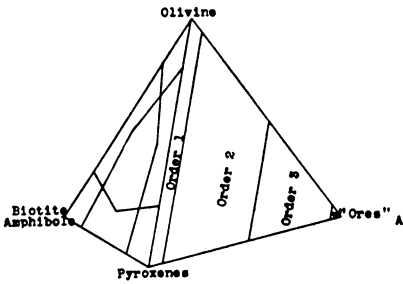


FIG. 17

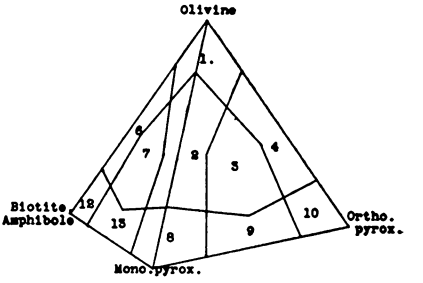


FIG. 18

FIG. 17.—Subdivisions of the tetrahedron of Class 4 into orders

FIG. 18.—Subdivisions of Orders 1 and 2, Class 4, into 15 families. Order 3 is subdivided similarly, but the corners represent olivine, biotite and amphiboles, pyroxenes, and the "ores." Order 4 has the various "ores" for corners.

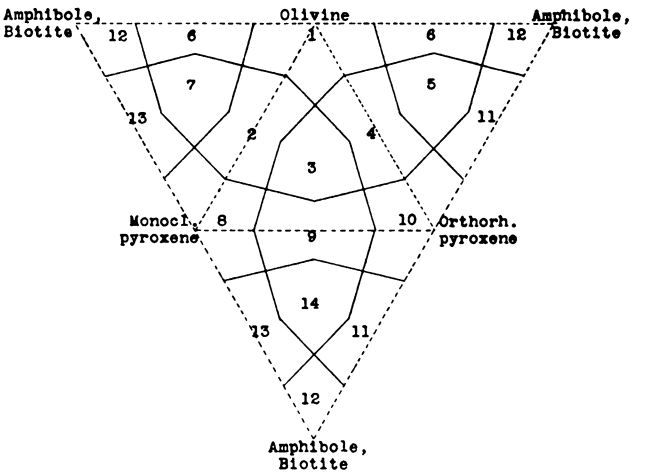


FIG. 19.—Family numbers in Class 4

The quartz-(or feldspathoid-) feldspar relations given by Lincoln are 100–96–67–33–4–0, and by Iddings[2] 100–62½–12½–0. Lincoln's division at 33 does not fit at all well into Fig. 15. Idding's divisions

[1] J. P. Iddings, *op. cit.*, II, 38, 40–41, 42, 44. [2] *Ibid.*, pp. 32, 38, 147, 228, 292.

fit quite as well as the divisions 100–95–50–5–0 proposed in the present paper, but the writer feels that a rock with 12½ per cent quartz (see Fig. 7 with 10 per cent) is too rich in quartz to be called a syenite. The writer would have no objection to making the divisions at 100–95–65–5–0 quartz (or feldspathoids), that is, on the basis of the 100–95–56–35–5–0 divisions with the omission of the 35 per cent line, but thinks it better to leave the divisions symmetrical. A rock with over 50 per cent quartz or feldspathoid is certainly distinct enough to deserve a separate place.

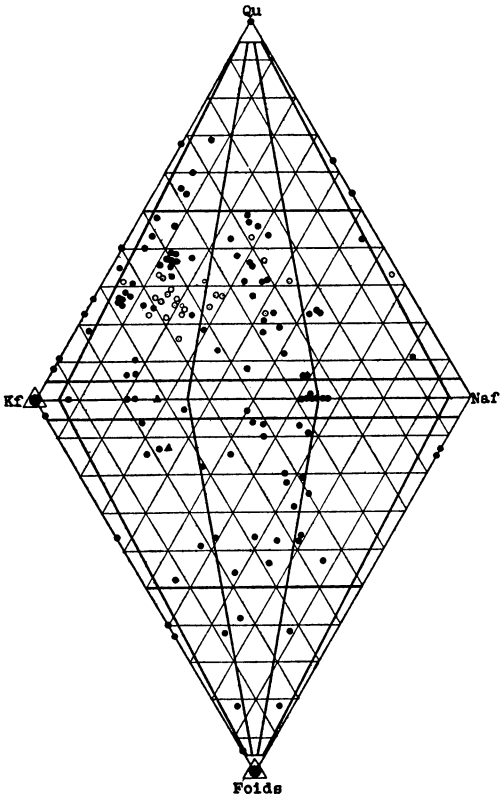


FIG. 20.—Rocks of Order 1 falling in Classes 1 to 3. Open circles are rocks of Class 1, dark circles rocks of Class 2, and triangles rocks of Class 3.

Class 4.—Owing to the absence of light constituents in Class 4 it was necessary to make the subdivisions on a different basis. After numerous attempts with different figures and different groupings of minerals, it was found that the compartments shown in Fig. 17 correspond most closely to the present subdivisions of the melanocratic rocks. The tetrahedron is subdivided into four orders by planes parallel to the left-hand face, each order representing an increasing amount of the ores. The division points for these planes, as in the other classes, are 0–5–50–95–100. To accommodate the rocks of the old classification, each order triangle

was opened out at one corner into a secondary tetrahedron, as shown in Fig. 18. The division points between families are at 0–25–75–100 to make the nomenclature conform to the older systems, and they are numbered, from the top and counterclockwise, from 1 to 15. The four corners, in Orders 1 and 2, represent respectively olivine, biotite and amphibole, monoclinic pyroxene, and orthorhombic pyroxene. In Order 3 the corners are olivine, biotite and amphibole, the pyroxenes, and the "ores" and other dark constituents. In Order 4, if thought desirable, they may be taken to represent the various ores; the writer, however, groups the ores in one family, for, considered as rocks, they are unimportant and hardly worth while separating. All of the families of the whole class, except Family 15, appear on the surface of the tetrahedron, Families 5 and 11 being at the back of Fig. 18, Family 14 underneath, and Family 15 in the center. Fig. 19 shows the tetrahedron opened out, Family 15 alone not appearing.

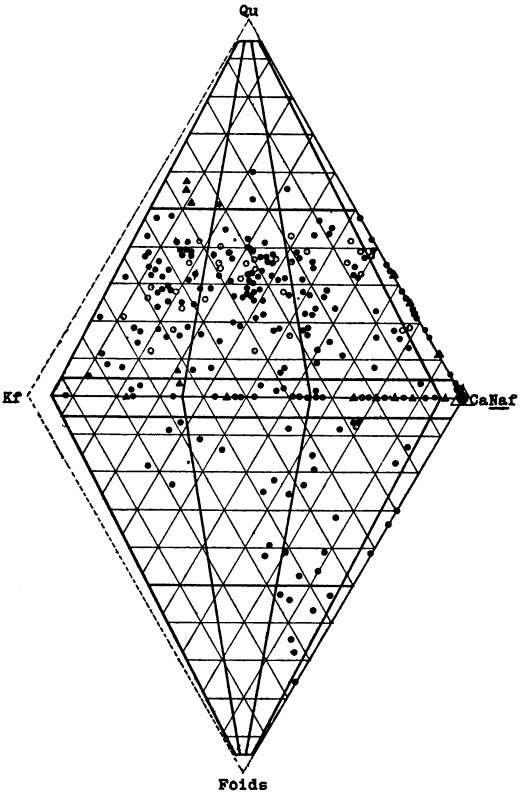


FIG. 21.—Rocks of Order 2 falling in Classes 1 to 3

ROCKS INCLUDED IN THE VARIOUS FAMILIES

Computed by the rules which follow, nearly 600 rocks are represented in Figs. 20 to 23. In these diagrams the rocks of the

same order, though of different classes, are shown together, the leucocratic rocks of Class 1 being represented by open circles, the moderately dark rocks of Class 2 by dark circles, and the dark rocks of Class 3 by triangles. The larger circles and triangles indicate that a number of mode-analyses fall together at these points. It will be seen that there are 32 families represented in Fig. 20, while in the other three figures there are only 24 to the order, as explained above.

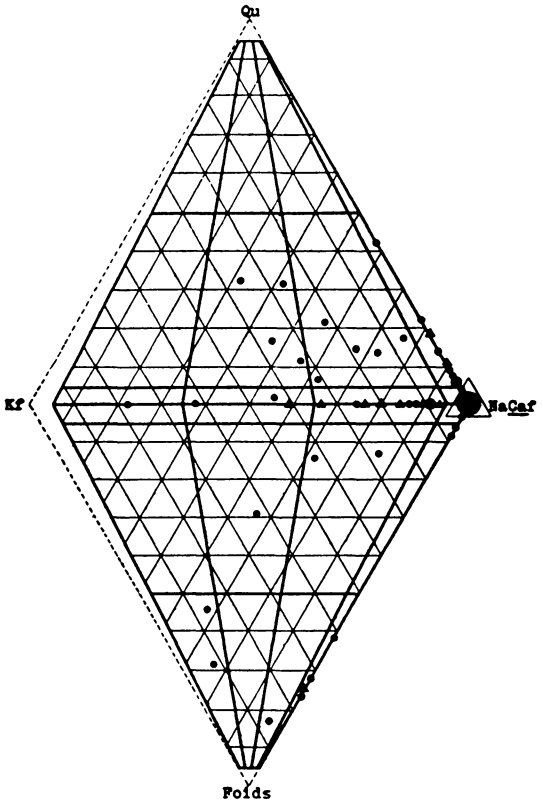


FIG. 22.—Rocks of Order 3 falling in Classes 1 to 3

In the following list about 500 computed rocks are arranged according to their old names followed by numbers indicating their positions in the present classification. No rocks are given having less than three mode-analyses unless of well-defined recent rocks. The first figure in the following numbers represents the class, the second the order, and the third (or third and fourth) the family. There are no orders in Families, 0, 1, 6, 11, 16, 21, 26, and 31, but since the rocks of these families are plotted in the double triangles of Order 1, their positions may be indicated by the figure 1. The figures in parentheses indicate the number of determined rocks which fell into that family. For example, 2123, 118, 422, 4210 represent respectively Class 2, Order 1, Family 23;

Class 1, Order 1, Family 8; Class 4, Order 2, Family 2; and Class 4, Order 2, Family 10. Numbers in bold-face type in the list indicate proper families among scattered (misnamed) rocks.

The rocks may seem rather scattered, but upon careful comparison it will be seen that they are not so far apart as they appear at first sight, for the lighter and darker rocks of Classes 2 and 3 in the gabbro and diorite families and of Classes 1 and 2 in the granite, syenite, monzonite, etc., families have ordinarily not been separated in petrographic reports. Much of the variation, of course, is due to the loose naming of rocks, and an andesine-bearing rock with augite may have been named gabbro, and a mesocratic labradorite-augite rock, diorite, etc. Thus the basalts in the list below—2315(4), 3215(1), 3315(5)—include 9 rocks belonging to Order 3, Family 15, the normal gabbro-basalt family, 4 of the rocks being mesocratic and 5 melanocratic. The remaining rock (3215) is a melanocratic andesine-bearing rock which should have been called an andesite.

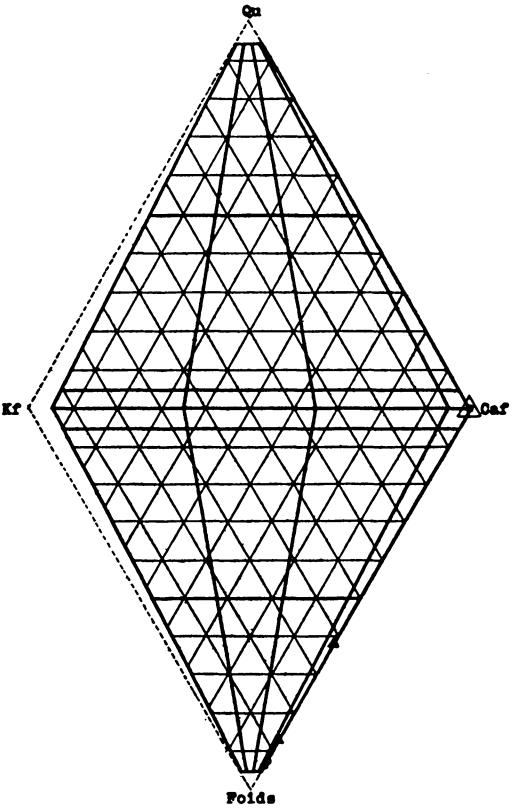


FIG. 23.—Rocks of Order 4 falling in Classes 1 to 3

Andesite **2215**(6), **3215**(1).
Aplite 128(3), 217(1), 223(1).
Alaskite 118(2), 117(2), 128(1).

Basalt **2315**(4), 3215(1), **3315**(5).
Basalt, Quartz **2310**(3).
Bostonite 2114(1), 2112(1), 2214(1).
Camptonite **3215**(2), 3214(1).
Comendite 217(1).
Covite 2123(1).
Diabase 2215(1), **2315**(9), 3215(1), **3315**(4).
Diorite 2214(2), **2215**(4), **3215**(2).
Diorite, Quartz **2210**(6), 238(1), 239(4), 2310(3).
Essexite 2320(1), 2315(1), 2324(2), 3213(1), 3314(2).
Gabbro 2314(1), **2315**(14), 3314(2), **3315**(5).
Gabbro, Quartz **3310**(3).
Gauteite 2320(1), 2330(1).
Granite, including alkali-granite **117**(4), 118(1), 123 (1), **127**(3), 128(2), 211(1), 212(4), **217**(20), 218(8), 219(1), **227**(21), 228(27), 229 (16), 2210(6), 238(1), 2310(1).
Granite-porphyry 212(1), 216(1), 227(2).
Granodiorite 228(2), **229**(8).
Grorudite 218(6), 219(2).
Hedrumite 2123(1), 2114(1), 2124(1).
Hornblendite **4212**(1), **4112**(1).
Heumite 2223(2), 2224(2).
Ijolite 2131(5).
Kersantite 2214(1), **3215**(2), **3315**(1).
Leucitite 2131(1), 2229(1), 2230(1), 2329(1), 2430(2), 3430(1).
Lindoite 228(5).
Laurdalite 2124(1), 2224(1).
Laurvikite 2118(1), 2123(1).
Leucite-tephrite 2223(5), 2224(4), 2229(3), 2327(1), 2230(2).
Malchite 3210 (3).
Melilite-basalt 2315(3).
Minette 216(2), 2111(1), 227(1), 2212(1), **2215**(1).
Minette, Soda 2114(1), 229(1), 2214(2).
Mariupolite 2125(2).
Missourite 3131(3).
Monmouthite 2131(1).
Monzonite **2213**(5), **2313**(1), **3213**(1), 3214(1).
Monzonite, Quartz **128**(4), 129(1), **228**(7), 229(4), 2214(1), **238**(3), 322(3).
Nephelite-syenite 1224(1), **2122**(3), 2123(3), 2124(1), 2126(1), 2129 (1), **2222**(3), 2223(1), 2225(1).
Norite 2214(1), 2314(3), 3214(1), 3314(5), **3315**(5).
Pantellerite 218(3).
Pegmatite 117(7), 118(2), 127(1), 129(4), 1210(2).
Phonolite **2122**(2).

Rockallite 215(2).
Rougemontite 2415(1).
Rouvillite 2225(1).
Shonkinite 2112(1), **3112**(1), **3212**(1).
Solvsbergite 2112(2), 2113(4), 2123(2).
Syenite 2111(2), 2113(3), 227(11), 228(7), 229(1), **2212**(2), 2312(1), 2313(1), **3212**(1), 327(1).
Tawite 2127(1).
Tinguaite **2122**(1), 2123(4), 2124(3), 2116(1).
Trachyte 216(1), 2113(1), 2123(1), **2212**(1), 2213(2).
Vulsinite 2213(1), 2222(1), 2223(2).
Yamaskite 3415(3).

CLASS NAMES

In a few cases the old classifications give special names to the dark varieties of feldspathic rocks. Thus shonkinite was definitely defined as a syenite with more than half of the constituents dark, although in the foregoing list one rock (2112) is mesocratic. In most cases, however, there are no special names for the dark feldspathic rocks, nor is it necessary to invent such, for the different varieties may be distinguished by prefixes. Since the rocks of Class 4 are separated from each other on an entirely different basis from the rocks of the other three classes and have special names they need not be considered here. To the other three classes the names suggested by Brögger—leucocratic, mesocratic, and melanocratic—may be prefixed. If desired, a rock may be called a leucogranite, meso-granite, or melano-granite, for example, instead of a leucocratic granite, mesocratic granite, etc. Meso, unfortunately, has been used as a prefix for Mesozoic rocks, but since the age classification of igneous rocks is no longer in use this would cause no confusion. Furthermore, since the normal rock usually falls in Class 2, the meso prefix is seldom necessary, and its name may be used without a prefix.

ORDER NAMES

The different orders may be indicated, when no special names exist for the various rocks, by the prefixes albite- (or soda-), sodic-, calcic-, and anorthite- (or lime-). Thus in the diorite family the rocks of the different orders would be albite- (or soda-) diorite,

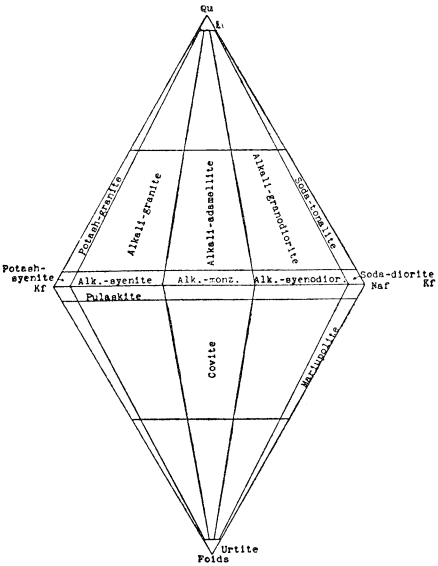


FIG. 24

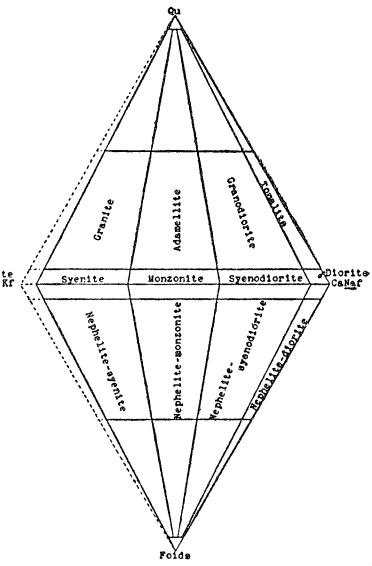


FIG. 25

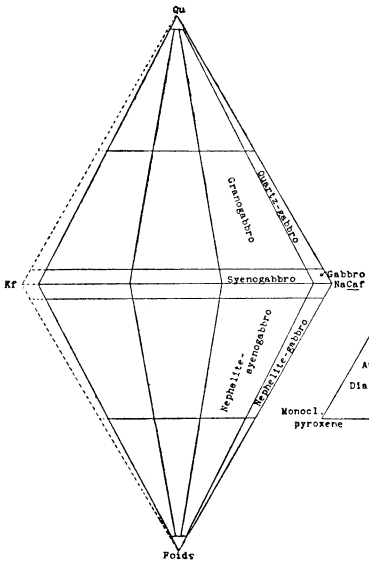


FIG. 26

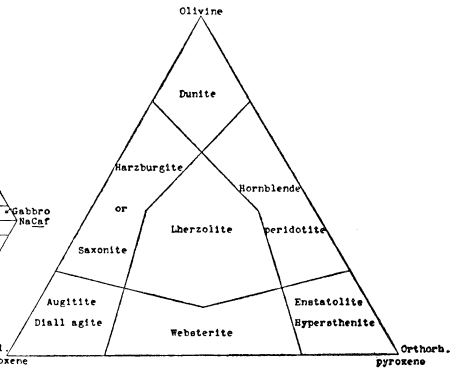


FIG. 27

FIG. 24.—Family names, Class 2, Order 1
FIG. 25.—Family names, Class 2, Order 2
FIG. 26.—Family names, Class 2, Order 3
FIG. 27.—Family names, Class 4, Order 1, Families 1, 2, 3, 4, 8, 9, and 10

sodic-diorite, calcic-diorite, and anorthite- (or lime-) diorite. As a matter of fact, these rocks in the old classification have special names, namely, soda-syenite, diorite, gabbro, and anorthite-gabbro, and, except the first, which more properly is an albite- (or soda-) diorite, should not be changed. The prefixes persodic, dosodic, etc., of the C.I.P.W. system cannot be used, since they apply to definite proportions of the constituents and not to those used here.

FAMILY NAMES

It is not the intention in this paper to name definitely all the families, those in Figs. 24 to 27 being given simply as examples. Most of the family names have been determined, and will be given in a succeeding paper. The family name should be that of a rock without abnormal constituents which occupies nearly the center-point of that family. Thus a garnet-bearing rock should not be chosen as a family representative if a non-garnetiferous rock is known, the garnetiferous rock being indicated by a prefix. The name should also be that of the plutonic rock, if such is known. Furthermore, if only one name is given to the rocks of the same family in the various classes, it should be given to Class 2; Class 1 will then be its leucocratic variety and Class 3 its melanocratic variety. It is not to be understood from this that the writer thinks it undesirable to name particular varieties, for it may be very desirable if they represent distinct types and if their relationships to known rocks are clearly shown; but if a new type differs only by the presence of a single abnormal constituent, that constituent should simply be used as a modifying name.

The reasons for using certain family names, such as adamellite for quartz-monzonite, tonalite for quartz-diorite, etc., will be given in a succeeding paper. Syenodiorite, syenogabbro, and granogabbro are introduced as new terms to fill definite positions, the last being the orthoclase-bearing variety of quartz-gabbro and analogous to granodiorite, the first two being the quartz-free varieties of granodiorite and granogabbro.

Sub-families in Orders 1, 2, and 3 are formed on the basis of the predominating dark or auxiliary constituent; thus under granite are the divisions biotite-granite, hornblende-granite, topaz-granite,

tourmaline-granite, etc. This applies whether the modifying constituent is a mafite or an auxiliary.

THE MINERAL GROUPS

It is not sufficient to divide the constituents of the rock into those that are light and those that are dark, but it is necessary to make certain definite groupings. The primary division, of course, is into quarfeloids and mafites. Under the former are included:

QUARFELOIDS

Quartz (Qu).
Potash feldspar (Kf), including orthoclase and microcline, and the orthoclase molecule in microperthite, anorthoclase, etc.
Plagioclase (Plag), including the albite molecule in anorthoclase as well as all plagioclases.
Feldspathoids (Foids), nephelite, leucite, sodalite, hauynite, noselite, melilite, primary analcite, primary cancrinite, eudialyte, etc.

The rear angle of the double tetrahedron represents the mafites. It is the position of the remainder after the quarfeloids and auxiliary constituents have been deducted.

MAFITES

Dark micas (biotite, phlogopite, etc.).
Amphiboles.
Pyroxenes (including uralitized pyroxenes).
Olivine.
Iron ores (magnetite, ilmenite, chromite, pyrite, hematite, etc.).
Cassiterite.
Garnet.
Primary epidote.
Allanite, zircon, rutile, and other dark minor accessories.

SECONDARY CONSTITUENTS

Secondary constituents are calculated as the originals from which they came. Thus ore replacements of the mafites are computed as mafites, kaolin as feldspar, chlorite as a biopyribole, cancrinite and analcite as feldspathoids, serpentine as a mafite, etc.

AUXILIARY CONSTITUENTS

Auxiliary constituents are constituents, mostly pneumatolytic or metamorphic, which may be used in the nomenclature as mineral modifiers in the formation of sub-families. Rocks containing these minerals may have independent names if desired. The auxiliary minerals are seldom of importance.

Topaz	Primary scapolite
Tourmaline	Muscovite
Cordierite	Lepidolite
Corundum	Zinnwaldite
Fluorite	Apatite, etc.
Andalusite	

It will be observed that most of the auxiliary constituents are light in color; they are, consequently, computed among the leucocrates. It is true that if this is done, tourmaline-granite will fall among the leucocratic rocks, but since this rock is aplitic and the mineral pneumatolytic, this is not undesirable.

Glass must be computed from an analysis. One can usually surmise its composition from the character of the phenocrysts and the appearance of the rock. When undetermined, the rock must be given a tentative name, such as hyaline-rhyolite, etc.

RULES FOR COMPUTING ROCKS FROM THEIR MODES

1. The sum of the minerals in the mode should be 100 ± 0.5. If less, recalculate[1] to 100. The sum of the leucocrates (quarfeloids plus auxiliary minerals) so obtained determines the class.

Class 1. Leucocrates form less than 95 per cent of the total rock.
Class 2. Leucocrates between 95 and 50 per cent.[2]
Class 3. Leucocrates between 50 and 5 per cent.
Class 4. Leucocrates less than 5 per cent.

2. Determine the orders in Classes 1, 2, and 3 directly from the Ab-An ratio, the division lines being 0–5–50–95–100. In rocks

[1] All of the necessary computations may be performed in an instant of time by means of a slide-rule.

[2] These classes are tentative. If thought desirable (see question 1, below), the rocks will be divided into five classes.

containing both anorthoclase and soda-lime feldspars, the three molecules Kf, Naf, and Caf are to be separated, and the orders determined by the total Ab-An ratio. (See above, under the heading "Orders," for an example of ciminite so separated.) In Class 4 the orders are determined by the percentage of "ores" and other dark minerals in the rock, the division points also being 0–5–50–95–100.

3. Determine the family. In Classes 1, 2, and 3 first recalculate the quarfeloids to 100. The amount of quartz (or feldspathoid) immediately determines the distance from the feldspar line. The separation points are 0–5–50–95–100. Now recalculate[1] the Kf plus plagioclase to 100, and determine the proper point on the Kf-Plag line. (If plotted graphically, the family is directly determined by the position of the intersection of the three lines. If the point falls very close to a division line, it may be necessary to compute its position accurately.) The separation points for Kf-Plag are 0–5–35–65–95–100.

In Class 4, Orders 1 and 2, recalculate the olivine, pyroxenes, biotite, and amphiboles to 100 and find the proper positions graphically, or find the position analytically by taking the ratio of the minerals of one corner to each of the others; thus augite to olivine, augite to hypersthene, and augite to biotite or amphibole. The division points are 0–25–75–100. In Class 4, Order 3, the corners represent olivine, amphibole and biotite, all pyroxenes, and the "ores" and other dark constituents. In Class 4, Order 4, the writer groups all the ores in a single family, but classifies the various hematite, ilmenite, magnetite, etc., ores as subfamilies. If desired they may be further separated. If accessory dark minerals, not used in the computation, are abundant, they determine subfamilies and may be mentioned in the rock name.

A few points to be observed.—Any percentage value falling exactly on a line should be moved in the direction of the center of the triangle. Thus a syenite with 5 per cent quartz is classified with granite, a rock with 95 per cent mafites belongs to Class 3,

[1] It is immaterial whether the orthoclase-plagioclase ratio is taken from the original values or from those reduced as quarfeloids to 100. The results are naturally the same.

and one with 95 per cent quarfeloids to Class 2; $Ab_{95}An_5$ belongs to Order 2 and Ab_5An_{95} to Order 3. If the divisions fall on the 50–50 line of quartz they are moved upward, or, with the Foids downward, toward the apex; that is, they are placed in Families 1 to 5 or 25 to 30. Along the plagioclase line, $Ab_{50}An_{50}$ is classed with the basic plagioclase, and 50–50 light-dark with the dark. Rocks falling on the line separating the two triangles, namely, on the feldspar line, should be classed on the quartz side, that is, on the normal side.

EXAMPLES

Example 1.—A granodiorite having the composition

Quartz	18.0	=23.1
Orthoclase	18.0	=23.1
Andesine (An_{70} An_{30})	42.0	=53.8
Total quarfeloids	78.0	
Biotite	12.8	
Hornblende	9.0	
Magnetite	.1	
Titanite	.1	
Total mafites	22.0	
	100.0	

Percentage quarfeloids=78. Rock belongs to Class 2.

$Ab_{70}An_{30}$ falls between 95 and 50. The order, therefore, is 2.

The family may be rapidly determined graphically, Plot 23.1 Qu, 23.1 Or, and 53.8 Ca*Na*f by measuring 23.1 upward from the base of the triangle toward Qu, and 23.1 from the right-hand inclined line toward the lower left corner. The intersection of the two lines will fall in Family 9 and determines the position of the rock. As a check, the point must also lie 53.8 from the left sloping line toward the lower right corner.

To compute the family analytically: From the presence of 23.1 per cent quartz, the family must lie between numbers 6 and 10, since there is more than 5 per cent and less than 50 per cent quartz. Further, the ratio $\frac{\text{Or}}{\text{Ca}Na\text{f}}=\frac{18}{42}=\frac{30}{70}$, and since the orthoclase is between 5 and 35 per cent, the family belongs in No. 9.

The rock number, therefore, is 229, that is, Class 2, Order 2, Family 9.

Example 2.—A syenite having

Kf	60.0		= 76.0
Ab_5An_3	18.0		= 22.8
Qu	1.0		= 1.2
Total quarfeloids		79.0	100.0
Biot	18.0		
Hbl	2.0		
Acces	1.0		
Total mafites		21.0	
		100.0	

Percentage quarfeloids to mafites 79, therefore Class 2.

$Ab_5An_3 = Ab_{62.5}An_{37.5}$, therefore Order 2.

Quartz less than 5 per cent, therefore between Families 11 and 15.

$\frac{Kf}{CaNaf} = \frac{60}{18} = \frac{77}{23}$, therefore Family 12. The rock number is 2212; that is, Class 2, Order 2, Family 12. The values 76, 22.8, and 1.2 are used in the graphical location of the rock.

Example 3.—A nephelite-syenite with

Kf	21.5		= 39.0
$Ab_{92}An_8$ Naf	31.0		= 61.0
$Ab_{92}An_8$ Caf	2.5		
Total feldspar		55.0	100.0
Neph	27.5		
Sodal	8.5		
Total feldspathoids		36.0	
Total quarfeloids			91.0
Aeg.-aug	5.0		
Biot	2.5		
Acces	1.5		
Total mafites			9.0
			100.0

Quarfeloid ratio 91. Class 2.

$Ab_{92}An_8$ . . . . . Order 2.

Foids to feldspars $= \frac{36}{55} = \frac{39.5}{60.5}$. Between Families 21 and 25.

$\frac{Kf}{CaNaf}=\frac{21.5}{33.5}=\frac{39.0}{61.0}$. Family 23.

Rock number is 2223. The values 39 and 61 are used in plotting the rock.

Example 4—A lherzolite with

Augite	45.0	= 47.4
Hypersthene	20.0	= 21.0
Olivine	30.0	= 31.6
Hornblende	3.0	100.0
Magnetite	2.0	
	100.0	

Since there are neither feldspars, feldspathoids, nor quartz, the rock must belong in Class 4.

The ratio of ferromagnesian minerals to ores is 98 : 2, therefore the Order is 1.

The ratio of augite to hypersthene is 45:20=69:31, therefore the family lies in the middle row and is either 1, 3, 9, or 15 (Fig. 19). The ratio of augite to olivine is 45:30=60:40, and the rock again lies in the middle line including Families 2, 3, 10, and 15. The ratio of augite to hornblende is 45:3=95:6, therefore it is in the front series of families including 1, 2, 3, 4, 8, 9, 10. Family 3 is the only one common to the three computations, consequently the rock number is 413.

Graphically the rock may be plotted by using the numbers 47.4, 21.0, and 31.6.

One of the advantages of this system of classification is that each thin section of the rock may be plotted independently; the center point of all the dots representing sections from a single rock-mass will represent the average. This is much more satisfactory than estimating the average from a number of sections which differ considerably in the amounts of the constituents. The various dots representing complementary rocks will fall in straight or branching lines, showing the course of differentiation.

Before publishing his second paper on this system of classification the writer desires the opinions of more petrographers than he has been able to consult personally. *He would be very glad,*

therefore, to receive at once answers to the following questions as well as further comments from all who are interested.

QUESTIONS

1. *Classes.*—Should there be a fifth class for rocks having approximately equal amounts of light and dark constituents? The limits would then be 0–5–35–65–95–100 instead of 0–5–50–95–100, as here proposed. The introduction of an extra class would add 104 families.

2. *Orders.*—Should Order 4 (Fig. 23), in which there are very few rocks, be combined with Order 3? Order 3 would then contain all rocks with plagioclase from labradorite to anorthite inclusive. This would make the subdivisions from Ab to An at 0–5–50–100, and would reduce the number of families by 72. Of course, if the fourth order is retained the pigeonholes need not be named until rocks occupying them have been found.

3. The line separating the granites, adamellites, etc., from the corresponding quartz-rich varieties is here taken at 50 per cent quartz. Should there be a dividing line here, or should granite, for example, include all rocks having from 5 to 95 per cent of quartz? As suggested above, the division line might be made at 65, making the lines 0–5–65–95–100.

4. In the older classifications albite is united with orthoclase for the alkali rocks. This would throw out Order 1, but in the older systems, with the introduction of lime, the soda molecules are divided into two parts, and orthoclase plus albite is contrasted with the lime-soda plagioclases. This division is not logical, but is it desirable? If such a division were made, Order 1 (Fig. 20) would be dropped and the alkali rocks would form Families 1, 6, 11, 16, 21, and 26 of the triangles now representing Order 2 (Fig. 21), and soda- and potash-rocks would have to be separated in the subfamilies. The double triangle would then have orthoclase+albite +microperthite+anorthoclase for the left angle of the base, while the right corner would be Ca*Na*f, Na*Ca*f, or Caf, depending upon the orders. Such a combination would simplify the placing of rocks containing microperthite, which is worth careful consideration, but the grouping is not so correct theoretically. All of the rocks

of Fig. 20 would then fall into the dotted compartments of Fig. 21. Computed modes, however, would be more difficult to place. As a matter of fact it is usually not difficult to separate the albite in microperthite from the orthoclase. Should this change be made, Family 6, for example, would become the family of the alkali-granites, and would contain potash-granite, alkali-granite, alkali-adamellite, alkali-granodiorite, and soda-tonalite. The latter would then again become soda-granite, the first potash-granite, and the intermediate rocks soda-potash granites. Covite, mariupolite, most essexites, etc., would fall in Family 21 without differentiation. Such a combination would reduce the number of families by 72, and if the anorthite were united in Class 3, as suggested above, the total reduction would be 144 families. Personally the writer is inclined to favor separating the feldspars into the Or, Ab, and An molecules.

5. Would it be desirable to indicate, in the name of the rock itself, that the mineral proportions have been determined, and that the rock falls into a certain compartment, for example by a slight change in the spelling, such as granyt, dioryt, etc.? Of course terms like monzonite BRÖGGER, theralite ROSENBUSCH, etc., might be used, but they seem cumbersome. (Granyte, dioryte, etc., cannot be used, since this spelling was suggested and used by Dana to contrast with the *-ite* endings of minerals.)

Appendix.—An alternative classification could be based upon four double tetrahedrons, representing four classes, according to the amounts of light and dark constituents, and each subdivided as in Fig. 27. The corners of the tetrahedrons would be quartz, Kf, Naf, Caf, and Foids, and the division points 0–25–75–100. There would be fewer varieties than in the preceding classification, and it would be much simpler, but the families would not correspond so closely to those in the old classifications as does the one given above.